DISTRIBUTION OF POTENTIAL IN SUSPENSION TYPE INSULATORS

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in
SUSPENSION TYPE INSULATORS.

A THESIS

PRESENTED BY

M. KALLIS

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PREFACE

This thesis is entirely original, no literature of any sort treating of this subject can be obtained and it is doubtful whether there is any published. We tried to carry out various methods, but some unforseen difficulty always arose which sometimes could be explained and eliminated, but sometimes could not. The plans of procedure were developed and tried as the work progressed.

Some works of this nature was carried out by Prof. Creighton of the General Electric Company, but his method, the Potentiometer method, which is explained in the contents of this thesis, is the method he used. In this way he obtained results which were not very reliable, but which, however, were accurate compared with the results we obtained by our methods. Since we did not have the facilities that the potentiometer determination requires, original work was attempted. As no results were obtained, we intended to construct a potentiometer, but since it could not be made in time for any experimental work, this could not be included.

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However, the negative results obtained may serve as a guide to any who may be interested in carrying the work to completion.

M. Kallis
E. W. Reede.

DISTRIBUTION OF POTENTIAL IN SUSPENSION TYPE INSULATORS.

: When a high voltage is applied to a suspension type high-tension insulators of two or more units of equal electrostatic capacities there is a greater drop in potential over the unit nearest the conductor than any of the others.

THEORETICAL EXPLANATION.

The only explanation of this phenominia that can be advanced at present is that leakage through the air effects, the apparent capacities of the units, and thus causes an unequal distribution of potential.

Figure 1, plate 6, shows what is possibly the static field surrounding the group of units under service conditions. Figure 2, plate 6, shows an equivalent arrangement of condensers in which condensers A - G, B - G, etc. in parallel with the units of the series, replace the leakage paths shown by the dotted lines in Fig. 1. The metal of the units at A and B with the porcelain between form a condenser which will be called A - B. In addition, the line and metal A, and the grounded metal at G with the intermediate air as a dielectric form a condenser A-G,

which is in parallel with the ramaining system of condensers. In a like manner the metal at B and the ground-metal at G form a condenser B - G, which is in series with the condenser A - B, and in parallel with the remaining arrangement of insulator units. Again, in the same manner, condensers B-G and D-G combine their capacities with the remaining arrangement. The result of this leakage capacity is to decrease the apparent capacities of the line end of the system, and to increase the capacities of the units at the ground end. As will be remembered, when a number of condenser units are connected in series, the drop over each will be universely proportional to its capacity. Therefor, if the apparent capacity of the units which are near the line be decreased, and those nearer the ground increased, the drops over the various units will not be equal, as they would be if, equal apparent capacities were obtained. For this reason, the drop over the unit near the line is much greater than that over any other, and that over the one at the grounded end of the system is least of all.

As has been pointed out, it is desirable to make the potential differences over the various units equal.

The only way to do this is to grade their capacities in such a way as to make their apparent capacities equal. The unit next to the line should have the greatest capacity, and that which is grounded the least.

DISTRIBUTION DETERMINATION.

There are two methods which may be suggested for measuring the drop over the individual units making up a suspension insulator. They are the electrostatic voltmeter and the potentiometer methods. The former will be considered first.

DETERMINATION BY MEANS OF THE ELECTROSTATIC VOLTMETER.

There are many difficulties to be overcome in order to obtain the actual potentials by means of an electrostatic voltmeter. Such a voltmeter must have capacity, and when this capacity is connected in parallel with the capacity of a unit, a redistribution of potential takes place, which is due to the raising of the apparent capacity of the combination. This effect is similar to that taking place when a low resistance voltmeter is used to measure the drop over a low resistance. The increasing of the apparent capacity of the unit lowers the drop over it and at the same time increases the drops over the others; so that, if the capacity of the voltmeter used is comparable in magnitude to that of the unit, the distribution is changed so much from the normal that no possible connection can be made for it.

The only means of partially eliminating this effect lies in the use of a voltmeter whose capacity is only a few per cent of that of the unit, so that the distribution of potential is only changed a like percentage. The smaller the ratio of the capacities the better.

The authors first intended to use the 25,000 volt scale of a Westinghouse 100,000 volt electrostatic voltimeter in measuring the drop over the units and the higher scale for obtaining the line voltage, but it was found that the capacity of the instrument when arranged for a lower scale reading was nearly equal to that of the insulator units. The capacity of the voltmeter when using the 25,000 volt scale was, .0000525 M.F. while those of the insulators varied from .00005 to .0000737 M.F. It would be impracticable to use this voltmeter because the drop over a unit would be changed from 40 to 50 percent.

The next plan suggested consisted of using a 1300 volt electrostatic voltmeter manufactured by Elliot Brothers of London England in connection with a multiplying capacity so that it could be calibrated

to read 26,000 volts. From rough measurements it was found that the capacity of this voltmeter was about .00005 M.F. To increase its range to 26,000 volts, or a multiplication of twenty, a series condenser of about .0000026 M.F. capacity must be used. The total capacity of the instrument would then be about .0000025 M.F. This value is about 5 percent of the capacity of the smallest insulator unit so that the distribution of potential would not be changed by very much.

This combination could not be used for a drop of less than 9,000 volts over each unit, as the scale of the instrument reads inaccurately below 9000 volts. Even with a difference of potential of 900 volts the multiplication factor must be lowered to ten, which would cause a difference between the measured and normal drop over a unit of about 10%.

The apparatus was constructed as shown in Plate II. The multiplying capacity consisted of two wooden discs 5 inches in diameter, covered with tin foil. These were placed upon wooden supports. By sliding the rods in their guides, the distance between plates, and hence the capacity could be varied so that it is possible to calibrate the instrument.

This condenser and the voltmeter were mounted upon a table as shown. The insulators were hung from a chain hoist which was fastened to the ceiling of the room. This was grounded by means of a wire running to a steam pipe. The apparatus was connected as shown in plate 7 and 8. One terminal of the voltmeter,(shown as a movable contact), was fastened to a piece of metal upon the end of a well seasoned stick of wood about six feet long. By reversing the 1,300 volt voltmeter connection from the grounded to undergrounded side of the insulators, and exchanging the terminals of the whole combination, eight cases of connection are possible. The reversing of the voltmeter terminals changed conditions because one terminal was insulated from the instrument case and connected to the inductor while the other was grounded on the case.

This method of measurement is not practicable as will be shown.

The deflections were as follows, for the various cases, with the movable point placed as indicated:-

CASE 1.

Movable contact to 1 - Deflection off scale, 2 - Full scale, 3 - Tendency to deflect, 4 - Zero, deflection.

CASE 2.

Movable contact to 1 - Small deflection, 2 - Small Deflection, 3 - Zero, 4 - Zero.

CASE 3.

Movable point to 1 - Tendency to deflect 2 - Tendency to deflect, 3 - zero, 4 zero.

CASE 4.

Movable point to 1 - zero, 2 - zero, 3 - Tendency to defledt, 4 - small deflection.

CASE 5.

Deflection off scale even if movable lead is disconnected entirely.

CASE 6.

Movable point to 1 - Deflection off scale, 2 - Full scale deflection, 3 - 3/4 scale deflection, 4 zero.

CASE 7.

Movable point to 1 - Deflection off scale, 2 - 1/2 scale deflection, 3 - 1/4 scale, 4 - zero.

CASE 8.

Movable point to 1 - Deflection off scale 2 - 1/2 scale, 3- Small deflection 4 - Tendency to.

NOTE: In these tests the multiplier plates were at least 2.5 feet apart and a voltage of about 13,000 was used.

From these indications it is evident that there was a complicated case of leakage and capacity effects. Later tests show that capacity was the principal cause of trouble. It was throught that a large amount of leakage occurred between the case and ground. This leakage path, if it existed, would cause the indications noted in some of the cases of connection.

In case 1 this leakage path is in parallel with the voltmeter, and when the movable contact is placed at 1, it would cause the voltmeter to deflect, which checks with the observations. At point 4 there should be no deflection because this path would be in parallel with the voltmeter and tend to lessen any tendency to deflect, which would be small as the plates were so far apart.

In case 2, the leakage path is in such a connection as to cause the effects noticed, namely:

very small or zero deflections in any position of the movable connection.

In case 3, the supposed leakage path is also in such a position as to cause the effects noticed.

In case 4, the leakage theory also gives cause for the observed results.

In case 5, there could be a circuit through the leakage path, the voltmeter and back to the undergrounded side of the line, which would cause a deflection no matter where the movable terminal is placed. This checks with observed readings.

In case 6, when the movable point is at 1, there could be a circuit through the leakage path, the voltmeter, and, to the ungrounded side of the line, which would give a large deflection.

When the movable contact is at 4 there would be no deflection because the voltmeter connection and the leakage path are on the same side of the line. This checks with observations.

In case 7, the leakage theory does not give cause for the observed readings.

When the movable contact was at 1, the instrument deflected off the scale; at this point the leakage path is directly across the line.

Also, in case 8, the leakage theory, does not give cause for observed readings. When connected to 1 the voltmeter deflected off the scale. With this connection the leakage path is in parallel with the voltmeter and series with the multiplying capacity, so a very small deflection should result.

In order to lessen this supposed leakage insulators were placed under the table legs. This did not effect the results in the least.

The next proceeding was to hang the voltmeter by paraffined cords from the ceiling. The arrangement was as shown in plate 18. All wood used was boiled well in paraffin. When the apparatus was arranged in this way, there was little chance for leakage to the ground.

The effects observed when this combination was used were as follows:-

CASE 1.

Movable point at 1 - Deflection off the scale,

2 - 1/4 scale deflection, 3 - zero deflection, 4 1/2 scale deflection.

CASE 2.

Movable point at 1 - Full scale deflection, 2 - small deflection, 3 - Tendency to deflect.

CASE 3.

Movable point at 1 - Half scale deflection, 2 - Tendency to deflect, 3 - Tendency to deflect, 4 - zero deflection.

CASE 4.

Deflection off of scale no matter whether the movable point is disconnected or not.

CASE 5.

Deflection off of scale as in case 4.

CASE 6.

Movable point at 1 - Full scale deflection, 2 - Three quarter scale deflection,- 3 quarter scale deflection, 4 - zero deflection.

CASE 7.

Movable point at 1 - Full scale deflection, 2 - Three quarter scale deflection, 3 - Tendency to deflect, 4 - zero deflection.

CASE 8.

Movable point at 1 - Deflection off of scale, 2 - Tendency to deflect, 3 - Tendency to deflect, 4 - Half scale deflection.

In case 1 capacity between the instrument case and the room, or insulators could cause the large deflection when the movable connection is placed at 1.

In case 2, the capacity assumed is in parallel with the voltmeter when the movable point is connected to 1, so that the observed full scale deflection is possible. Also, when connection is made to point 4, this capacity is in such a connection, as to allow a zero deflection.

In case 3, the observed results are entirely possible, as any capacity effect, as above, should make no difference in the readings.

The possibility of the observation, in case 4, is questionable according to the above assumption, but seems to be a reality. Here the capacity is directly across the line in any position of the movable contact.

In case 5, the effects are the same as when the instruments were mounted on the table and check with the possible deflections according to the assumption made above.

In case 6, the results are possible when there is such a capacity effect.

In case 8, the results are the same as when the voltmeter was mounted upon the table, and are questionable according to the above theory.

The observations as given above seem to show, that, as leakage should be practically eliminated when the instrument is suspended, the freak results must be caused by some complicated capacity effects. The capacity pointed out is probably the largest but by no means the only one. The deflections beyond the range of the scale show that the case - room capacity must be larger than the capacity of the multiplying condenser when the plates are moderately close together.

When the connections are as in case 3, the capacity to the voltmeter case has no effect. For this reason it would seem possible to obtain results in this way. This method was tried but consistant readings were not obtained. The voltmeter was adjusted for a multiplication of 20, that is, to read 36,000 volts, and a line voltage of 26,000 volts was used.

When the movable point was connected to 2, there was a reading of 20,400 volts (1020 x 20), when connected to 3, a reading of 3,200 volts (160 x 20). Subtracting 20,400 from 26,000 gives 5,600 for the drop over the lower unit. The voltage over the middle unit is 17,200 and the top one 3,200. It is evident that these results are not correct.

Calibration data was taken for this combination and was as follows:-

Voltmeter Readings.	Actual Voltage.
1300 x 20 = 26,000	26,000
1255 x 20 = 25100	24,000
1215 x 20 = 24,300	22,000
1180 x 20 = 23,600	20,000
1120 x 20 = 22,400	17,500
1070 x 20 = 21,400	15,375

using this data in correcting the distribution taken above gives results that seem farther from the truth than those given. This shows that the calibration of the instrument cannot be depended upon.

Since the determination of the potential distribution cannot be obtained by means of an electrostatic voltmeter some other method must be developed.

DETERMINATION BY MEANS OF POTENTIOMETER.

In the potentiometer method of measuring distribution of potential, a high resistance of a megohm or more is connected across the line. This resistance must be uniformly wound and have all points of the winding accessable. Movable connections, connected to the metal parts of the units are placed in such a position that no current flows through them to the resistance, except those to the line and grounded sides of the insulators. The potential difference between these contacts is measured by the fraction of total resistance included between them, times the line voltage. The point of equal potential on the resistance coil may be located by observing if there is a spark discharge upon connecting. Such a combination as this is shown in Plate 9.

The problem in this method is to eliminate leakage as far as possible between parts of the coils. Such leakage shunts part of the resistance and causes an error in determination.

CAPACITY MEASUREMENTS.

As has been stated above, the capacities to be dealt with are of very small magnitude. A great amount of trouble was encountered in finding a method applicable to their measurement. Two different methods were tried, but at best, only approximate results were obtained.

The first method tried was that of the comparison of direct deflections of the galvanometer. The apparatus used was a charge and discharge key, a standard condenser of .05 M.F. capacity and a very sensitive wall type galvanometer, manufactured by Leeds Northrup & Company.

The high direct current voltage used when obtaining galvanometric readings for the discharge of the insulators was taken from a storage battery. The low voltage used with the standard condenser, for determining the galvanometer constant, was obtained from one dry cell.

The apparatus was connected as shown in Plate 10. When the key was thrown in one direction, the capacity connected being either standard or insulator,

is charged; when in the other direction, is discharged through the galvanometer.

The galvanometer constant was obtained by using the .05 M.F. condenser and a pressure of about one volt. The computation of this constant follows. We have the fundamental formula for the relation of capacity, voltage, and quantity of charge in a condensor, $Q = C E$, where Q = quantity of charge, C = capacity, and E = difference of potential between plates. Now, when a condenser is discharged through a ballistic galvanometer, the quantity of electricity passing is proportional to a constant times the deflection or $K D$. Where K = a constant and D = the deflection. Therefor, $K. D. = Q$ and substituting above $K D = C E$. If D, C and E are known, K can be solved for.

When two or three insulator units were connected in parallel and a pressure of from 200 to 400 volts was used, a deflection upon discharge of about the same magnitude as that obtained when getting the galvanometer constant was obtained. From the formula above we can solve for C as we have determined K and know D and E. Dividing the capacity thus obtained by the number of

insulator units in parallel gives us the average capacity of each.

The capacity measurements by this method could not be made very accurate on account of the small galvanometer deflections obtained. However, it might be possible to get greater accuracy by the use of a higher voltage, but this was not at hand.

The direct deflection method was only used in the determination of the capacity of the large Thomas insulators shown in Plate 1, because it was early decided that the determinations could not be made accurately. The capacity of the Thomas insulators determined as above is about .000057 M.F. The results obtained varied, the maximum difference from the average being 17-1/2 percent.

The next method developed was the "high frequency method". An electric tuning fork of 15,000 periods per minute was used to charge and discharge the capacity. This fork had platinum contacts upon its extremities which engaged small platinum buttons. During one part of a period one contact engages its button and the condenser is charged and during the other part,

the other brush was in contact with its button, and short circuits the capacity. Thus the capacity is charged and discharged 15,000 times a minute. This combination is really a double throw key with the fork as its middle point and the buttons as contacts.

The apparatus was connected as shown in plate 5. The charging content for the condenser flows through the galvanometer. A voltage of from 6 to 10 volts when used with a single insulator unit gives a large galvanometer deflection of from 16 to 18 cm. Because of the high ratio between the capacity of the standard condenser (.025 M. F.) and that of the insulator unit, it was found necessary to use a low voltage of from .01 to .03 volt with the standard to give the same deflection as with the insulator and higher voltage. This low voltage was obtained by passing current from a storage cell through a standard .01 W resistance; the current being known, the resistance drop can be computed accurately.

In order to be able to change from the insulators to the standard and low voltage easily and quickly, four single pole double throw switches were used as shown.

Single pole switches were used in preference to double pole because any capacity or leakage effects may be lowered materially.

The procedure in taking a reading is as follows:- The deflection due to the charging current of the insulator was taken and the voltage which was applied read, and then the switches were thrown to the low voltage and standard capacity. The current through the resistance in the auxiliary circuit, and therefore the drop over it was varied by means of carbon pile rheostats placed in the circuit. When the drop over the resistance was such that the deflection of the galvanometer was the same as when the insulator and higher voltage was used, the ammeter was read and the applied voltage computed. As the deflections when the high voltage and insulator was used were the same as for the standard condenser and low voltage, the capacities must be in the inverse ratio of the voltage used for charging.

A great deal of trouble was experienced because the galvanometer was not dead-beat and due to changes in the fork contacts would swing over a wide range, making accurate reading impossible.

This was never completely eliminated.

One way which was tried consisted of using a thermo-electric couple to deflect the galvanometer. This was not successful, A small thermo couple of copper and contantin wire was mounted in contact with a very fine carbon filiament, such as is used in two candle power incandescent lamps. The whole was placed in a small box to avoid the effects of air currents. The carbon filament was connected in series with the charging circuit and the couple across the galvanometer. It was hoped that the heating effect of the small charging current upon the carbon filament would cause sufficient rise in temperature to effect the couple and deflect the galvanometer. This combination should integrate the variations in the current and cause a constant deflection, but it was found that the galvanometer gave no deflection whatever.

The difficulty was finally partially solved by placing two damping coils on the galvanometer. Even with this damping effect, there were great variations in deflection due to changes in the fork contacts.

The weather was found to have a great effect upon the constancy of the galvanometer deflections obtained. On damp days it was nearly impossible to get consistant results.

It was found that when the double throw potential switch was thrown to the high voltage side, the galvanometer gave a large deflection when no capacity was connected in the circuit. There was also, a moderate deflection when the switches were thrown to the low voltage and standard condenser, when no current was passing in the .01 W resistance. These deflections may have been carried by thermo-electric action or leakage, though the latter is not probable, because of the low voltage used, and the fact that no potential was impressed in the second case. It is possible that these effects were caused by the friction of the contacts of the fork upon the hard rubber surrounding the metal buttons. The above deflections were taken as zero readings. These readings sometimes amounted to several times the deflection due to the charging of the capacity. The condition for the zero reading with the insulator as capacity and the

higher voltage was with the condenser switches open and the potential switch closed upon the high voltage side. That for the second zero reading was with the potential switch closed on the low voltage side and the capacity switch closed to the standard condenser, and no current flowing in the auxiliary circuit.

The capacities determined are probably in error quite a large percent on account of the capacity effect of the connections which could not be seperated more than two or three feet. However, this error is practically constant in all measurements, and as the results to be obtained are only comparative, this makes little difference.

This method of measurement gives results which check quite well with those obtained by the direct deflection method for the Thomas insulators. The average results for those units was .000057 M.F. by the direct deflection method, and .0000613 M.F. by the high frequency method. The difference in results amounts to about 5%.

The final average results for the various measurements of capacity were as follows:-

Large Thomas insulators, (Plate 1), per unit .0000613 M.F.; Small Thomas Insulators, (Plate 2), per unit .0000737 M.F.; Ohio Brass Company insulators, (used on the Chicago Sanitary District transmission line), per unit, .000 456 M.F.; Locke insulators, (Plate 3), per unit, .0000742 M.F.; 100,000 volt Westinghouse electrostatic voltmeter, 100,000 volt scale, full deflection, .0000371 M.F.; 25,000 volt scale, .0000525 M.F.

After measuring what was supposed to be the capacity of a 2,300 volt electro-static voltmeter, it was found that the fuses in the instrument were burned out and that in reality the capacity of the wires connecting to it were being measured. These results may show the nearly constant error due to the capacity of these wires. The capacity was found to be .000021 M.F.

The high frequency method of capacity measurement could be made very accurate by the use of a commutator with large brushes, and no insulation projecting where the brushes can touch it.

DATA.

DIRECT DEFLECTION METHOD OF CAPACITY MEASUREMENT.

Large type Thomas insulators, (Plate 1).

Determination of galvanometer constant.

Deflections, cm.:- 2.48, 2.5, 2.52, 2.52, 2.52 average 2.508 cm. Standard condenser .05 M.F. Voltage applied .972

Constant .00194

Two Units in Parallel

Deflection, cm.:- 1.99, 1.98, 1.98, 1.97, 2.02, 2.02, 1.98, 1.98, average 1.99 cm. Voltage applied 356.5 capacity $\frac{.000108}{2}$ = .000054 M.F. each.

Three Units in Parallel

Deflection cm.:- 2.5, 2.6, 2.6, 2.58, average 25.82 cm. Voltage applied 356.5 volts. Capacity, $\frac{.00014}{3}$ = .000046 M.F. each.

DETERMINATION OF GALVANOMETER CONSTANT.

Deflection, cm.:- 2.7.4, 2.74, 2.75, 2.72, 2.76, 2.7.4 average 2.741 cm. Voltage applied 1.116, Standard condenser .05 M.F. Constant .00203.

TWO UNITS IN PARALLEL.

Deflection, cm.:- 2.71, 2.7, 2.7, 2.7, average 2.7 cm.

Voltage applied, 405. Capacity $\frac{.000135}{2}$ = .00067 M.F.

THREE UNITS IN PARALLEL.

Deflection, cm.:- 3.75, 3.72, 3.7, 3.71, 3.72, average 3.72, cm.

Voltage applied, 405, Capacity $\frac{.000186}{3}$ = .000062 M.F. Each.

Average capacity of these units .000057 M.F.

HIGH FREQUENCY METHOD.

Weston 0 - 5 Ammeter #106, standard .01 W resistance and standard .025 M.F. condenser used in all tests.

LARGE THOMAS UNITS. (Plate 1)

Voltage applied to insulators, 6.04

Deflections, cm.	Deflection cm.
High voltage, insulators	Low voltage - Standard Condensers
Zero reading 16.8	Zero reading 24.5
Final reading 11.4	Final reading 19.1
Def. 5.4	Def. 5.4

Current in resistance 1.4 amp.

Capacity $\frac{.014 \times .025}{6.04} = .000058$ M.F.

17.3	24
12.2	18.9
5.1	5.1
Current 1.4 amp.	Capacity, .000058 M.F.
18	24.6
12.9	9.5
5.1	5.1
Current ,1.34 amp.	Capacity .0000565 M.F.
18.2	23.8
12.7	18.3
5.5	5.5

Current 1.55 amp. capacity, .0000641

$$\begin{array}{r} 17.2 \\ \underline{11.8} \\ 5.4 \end{array} \qquad \begin{array}{r} 23.5 \\ \underline{18.1} \\ 5.4 \end{array}$$

Current 1.55 Amp. Capacity .0000641 M.F.

VOLTAGE APPLIED TO INSULATORS, 10.2

$$\begin{array}{r} 12.7 \\ \underline{3.3} \\ 9.4 \end{array} \qquad \begin{array}{r} 23 \\ \underline{13.6} \\ 9.4 \end{array}$$

Current, 2.725 Amp. capacity .0000668 M.F.

$$\begin{array}{r} 13.1 \\ \underline{3.9} \\ 9.2 \end{array} \qquad \begin{array}{r} 24 \\ \underline{14.8} \\ 9.2 \end{array}$$

Current, 2.535 Amp. capacity, .0000621 M.F.

$$\begin{array}{r} 13.5 \\ \underline{4.5} \\ 9 \end{array} \qquad \begin{array}{r} 24 \\ \underline{15} \\ 9 \end{array}$$

Current, 2.5 Amp. capacity, .000613 M.F.

SMALL THOMAS UNITS. (Plate 2).

Voltage applied, 7.84 Volts.

Deflections, cm.	Deflections, cm.
Zero reading, 7.2	Zero reading 1.5
Final reading 15.25	Final reading 9.55
Def. 8.05	Def. 8.05
Current, 2.26 Amps.	capacity .000722 M.F.
8	.5
16.9	8.4
7.9	7.9
Current, 2.34 Amps.	Capacity, .000747 M.F.
8.9	.5
12.2	8.8
8.3	8.3
Current, 2.485 Amp.	Capacity, .0000774 M.F.
6.4	1.3
14	8.9
7.6	7.6
Current, 2.29 Amp.	Capacity, .000073
6.75	1
14.65	8.9
7.9	7.9
Current, 2.335 Amps.	Capacity .0000712

Average Capacity of Units, .0000737 M.F.

OHIO BRASS COMPANY UNITS

(Used upon Chicago Sanitary District Transmission line)

Voltage Applied, 6 volts.

Deflection, cm.	Deflection cm.
Zero reading 9.2	Zero reading 1.6
Final reading 12.9	Final " 5.3
Def. 3.7	Def. 3.7
Current, 1.09 Amp.	Capacity, .000046 M.F.
9.15	1.85
12.7	5.4
3.55	3.55
Current, 1.08 Amp.	Capacity, .0000456 M.F.
8.9	1.65
12.75	5.5
3.85	3.85
Current, 1.1. Amp.	Capacity, .0000464 M.F.
8.55	1.65
12.8	5.9
4.25	4.25
Current, 1.15 Amp.	Capacity, 0000485 M.F.
8.5	1.75
12.6	5.85
4.1	4.1
Current, 1.17 Amp.	Capacity, .0000495 M.F.

Voltage Applied, 9.85.

13.5	1.9
20	2.4
6.5	6.5
Current, 1.86 Amp.	Capacity, .0000473 M.F.
13.55	2.15
19.45	8.05
5.9	5.9
Current, 1.76 Amp.	Capacity, .0000446 M.F.
13.5	2
9.75	8.25
6.25	6.25
Current, 1.8 Amp.	Capacity, .0000456 M.F.
13.25	2
9.45	8.2
6.2	6.2
Current, 1.8 Amp.	Capacity, .0000456 M.F.
13.	2
19.5	8.5
6.5	6.5
Current, 1.875	Capacity, .0000476 M.F.
13.1	2.1
9.25	8.25
6.15	6.15
Current, 1.79 Amp.	Capacity, .0000455 M.F.

Average Capacity, .0000456 M.F.

LOCKE UNITS, (Plate 3).

Voltage Applied 9.85.

Deflection cm.		Deflection, cm.	
Zero reading	13.5	Zero reading	2.25
Final reading	19.85	Final reading	8.6
Def.	6.35	Def.	
Current, 1.8 Amp.		Capacity, .0000456	
	13.75		2.25
	20.25		8.75
	6.35		6.35
Current, 1.8 Amp.		Capacity, .0000456 M.F.	
	13.75		2.3
	20.25		8.8
	6.5		6.5
Current, 1.83 Amps.		Capacity, .0000 465 M.F.	
	13.65		2.1
	20.35		8.8
	6.7		6.7
Current, 1.88 Amp.		Capacity, .0000478 M.F.	
	13.85		3
	20.75		9.9
	6.9		6.9
Current, 1.92 Amps.		Capacity, .0000487 M.F.	
	13.85		2.2
	20.25		8.85
	6.65		6.65

Current, 1.935 Amp. Capacity, .000049 M.F.

Average Capacity, .0000478 M.F.

WESTINGHOUSE ELECTROSTATIC VOLTMETER.

Full scale deflection, 100,000 volt scale.

Voltage applied, 9.84

	Deflection, cm.	Deflection, cm.
Zero reading,	13.75	3.75
Final reading	8.5	8.5
Def.	5.25	5.25

Current, 1.45 Amp. Capacity, .0000368 M.F.

13.75	4.1
18.8	9.15
5.05	5.05

Current, 1.43 Amps. Capacity, .0000367 M.F.

13.75	3.75
18.5	8.5
4.75	4.75

Current, 1.44 Amp. Capacity, .0000367 M.F.

13.75	3.75
18.75	8.75
5	5

Current, 1.57 Amp. Capacity, .00004 M.F.

13.75	3.4
18.7	8.35
4.95	4.95

Current, 1.4 Amp. Capacity, .0000361 M.F.

FULL SCALE DEFLECTION, 25,000 Volt Scale.

Voltage applied 9.84

Deflection cm.		Deflection cm.	
Zero reading	10	Zero reading	4.1
Final reading	14.5	Final reading	8.6
Def.	4.5	Def.	4.5

Current, 1.25 Capacity, .0000514 M.F.

9.95	4.5
14.9	9.45
4.95	4.95

Current 1.28 Amp. Capacity, .0000526 M.F.

10.25	4.4
14.65	8.8
4.4	4.4

Current, 1.28 Amp. Capacity, .0000526 M.F.

10.35	4.6
14.65	8.9
4.3	4.3

Current, 1.29 Amp. Capacity. .000053 M.F.

10.1	4.6
14.5	9
4.4	4.4

Current 1.29 Amp. Capacity .000053 M.F.

Average Capacity, .0000525 M.F.

ELLIOT 2,300 VOLT ELECTROSTATIC VOLTMETER.

Note:- The instrument fused were burned out, so the capacity measured was that of the connecting wires. This gives the probable error in all the above determinations.

Voltage Applied, 9.9 Volts.

Deflection, cm.		Deflection cm.	
Zero reading,	15.2	Zero reading	3.25
Final reading	18.4	Final reading	6.45
Def.	3.2	Def.	3.2

Current .76 Amp. Capacity, .0000192 M.F.

15.25	3.8
18.7	7.25
3.45	3.45

Current, .86 Amp. Capacity, .0000227 M.F.

15.1	5.6
18.6	9.1
3.5	3.5

Current, .75 Amp. Capacity, .000019 M.F.

15.3	5.15
18.8	9.65
3.5	3.5

Current, .82 Amp. Capacity, .0000207 Amp.

Average capacity of leads, .000021 M.F.

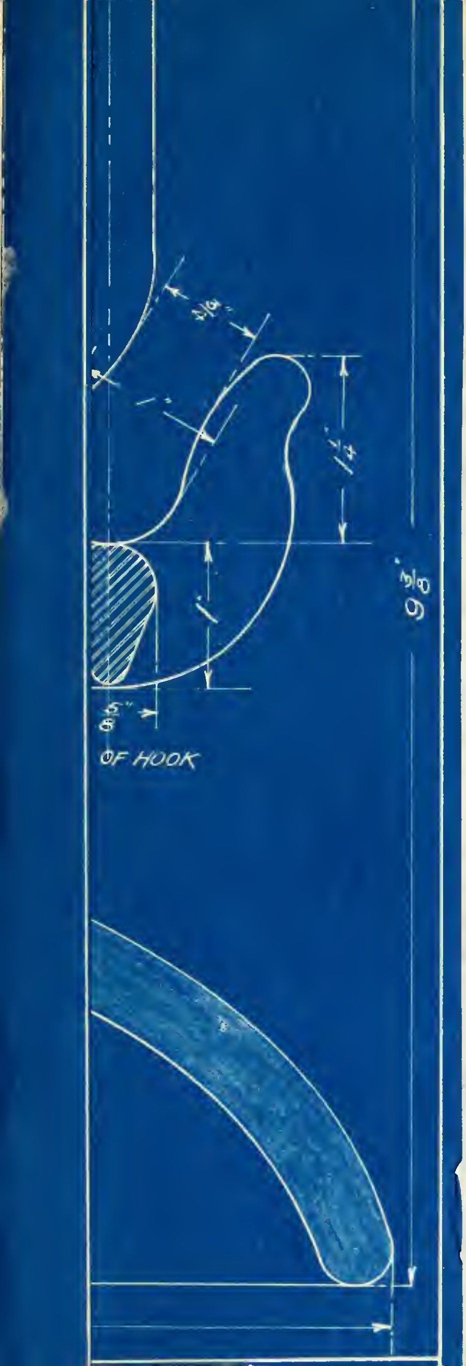
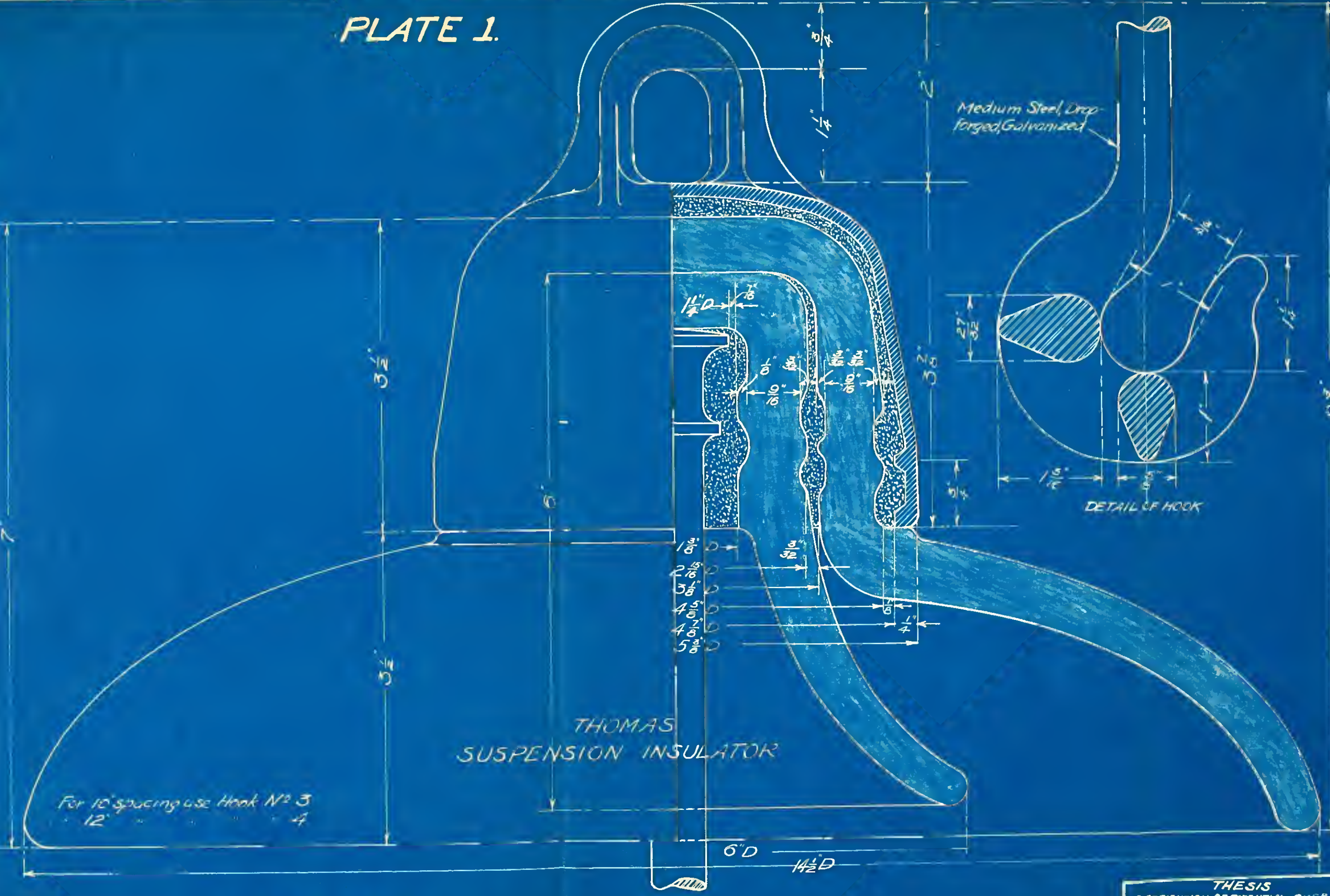

3/4"
1"
1 1/4"
1"
9 3/8"
9/16"
OF HOOK

PLATE 1.

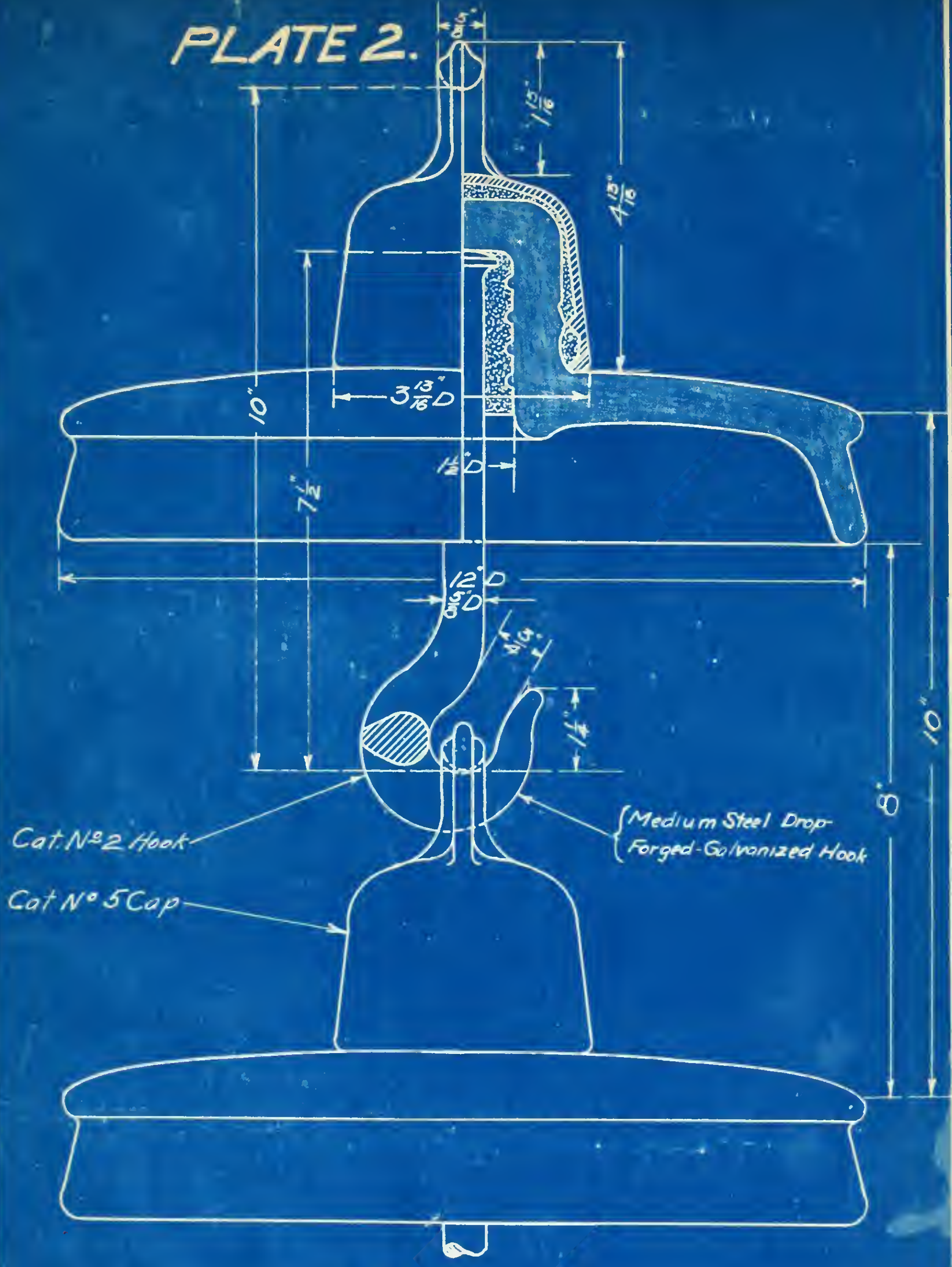


THOMAS SUSPENSION INSULATOR

CAT. No 2052

THESIS
DISTRIBUTION OF POTENTIAL OVER
HIGH TENSION INSULATORS
BY Kelley & Rueda 1910

PLATE 2.

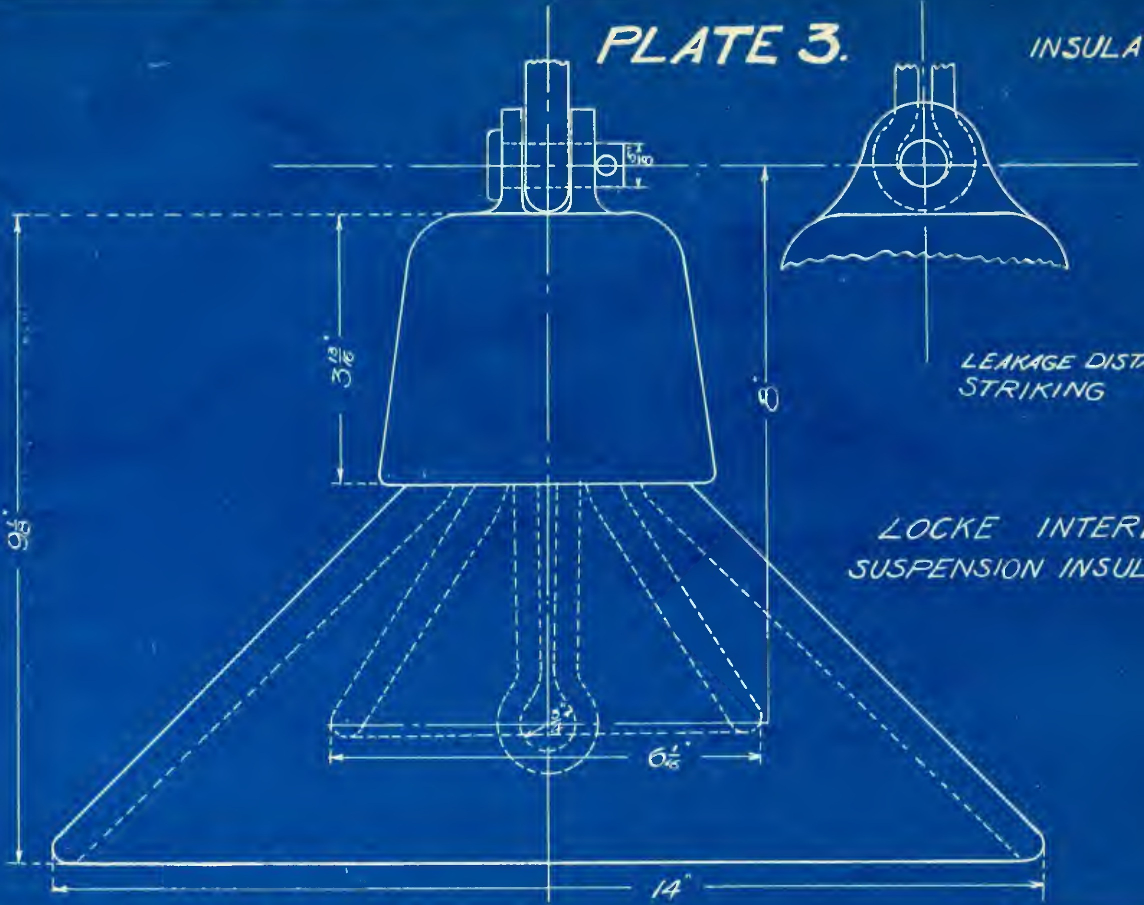


THOMAS
SUSPENSION INSULATOR
CAT. No 1060

THESIS
DISTRIBUTION OF POTENTIAL OVER
HIGH TENSION INSULATORS
BY Kallis + Ruede 1910

PLATE 3.

INSULATOR NO. 273



LEAKAGE DISTANCE 24"
STRIKING " 4 1/2"

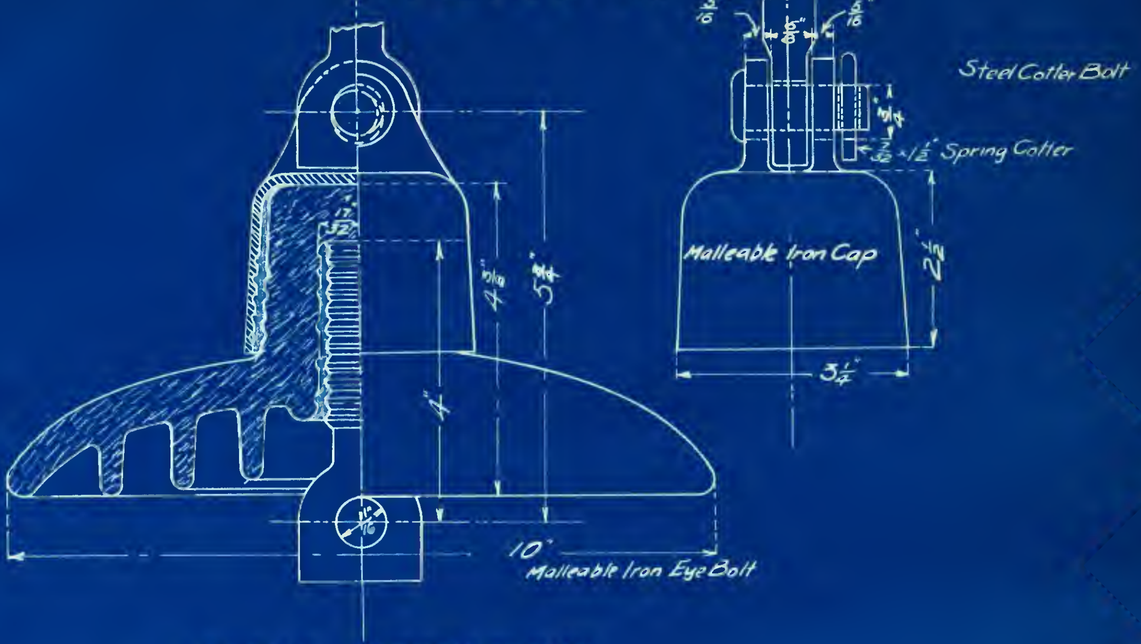
LOCKE INTERLOCKING
SUSPENSION INSULATOR

Note:- 5 ARE RECOMMENDED
FOR 100,000 VOLTS

THESIS
DISTRIBUTION OF POTENTIAL OVER
HIGH TENSION INSULATORS
BY Kallis + Ruede 1910

PLATE 4.

INSULATOR NO.

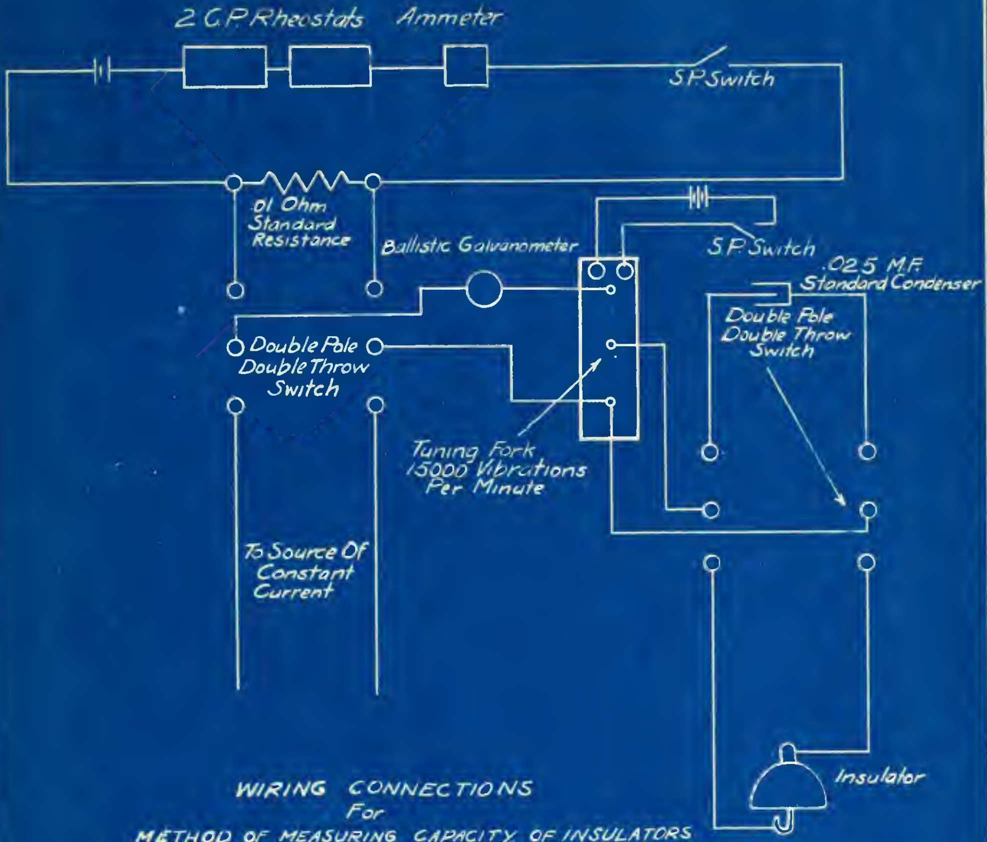


LOCKE INTERLOCKING
SUSPENSION INSULATOR

Note:
8 ARE RECOMMENDED
FOR 100,000 VOLTS

THESIS
DISTRIBUTION OF POTENTIAL OVER
HIGH TENSION INSULATORS
BY Kallis + Ruede 1910

PLATE 5.



WIRING CONNECTIONS
For
METHOD OF MEASURING CAPACITY OF INSULATORS
BY COMPARISON WITH STANDARD CONDENSER
IN COMBINATION WITH STANDARD RESISTANCE

THESIS
DISTRIBUTION OF POTENTIAL OVER
HIGH TENSION INSULATORS
BY Kallie + Ruede 1910

PLATE 6.

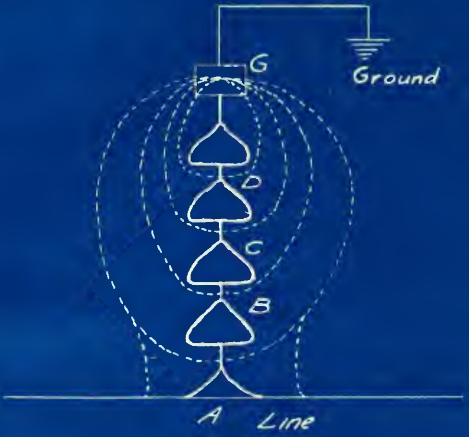


FIG. 1.

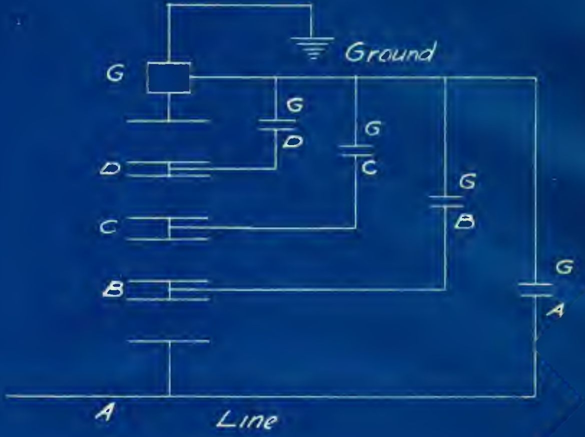
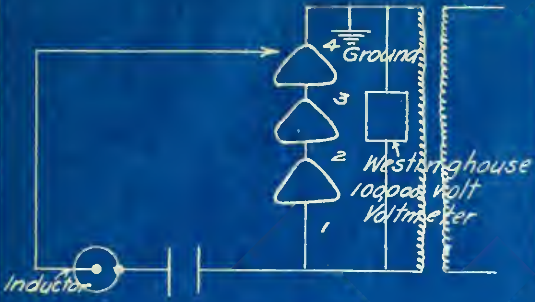


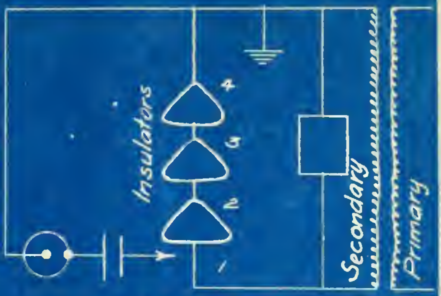
FIG. 2.

THESIS
DISTRIBUTION OF POTENTIAL OVER
HIGH TENSION INSULATORS
BY Kohler & Reed 1910

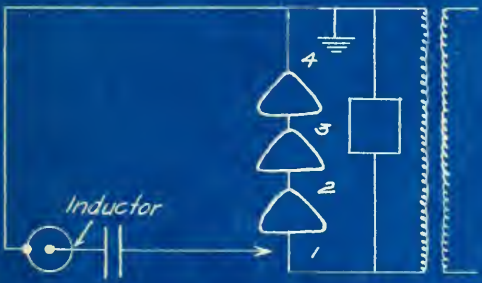
PLATE 7.



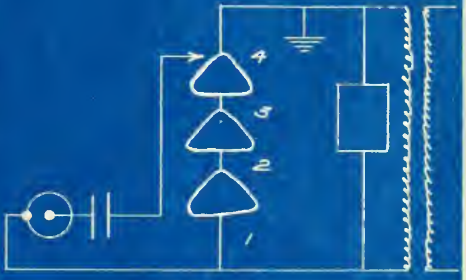
CASE 1.



CASE 2.



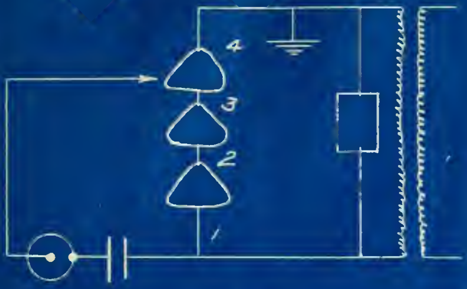
CASE 3.



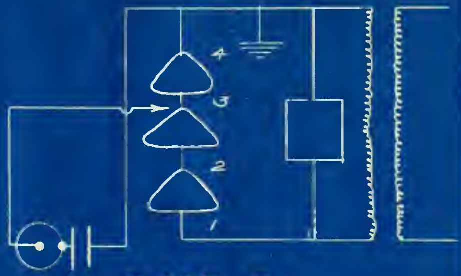
CASE 4.

THESIS
DISTRIBUTION OF POTENTIAL OVER
HIGH TENSION INSULATORS
BY Kallie + Ruede 1910

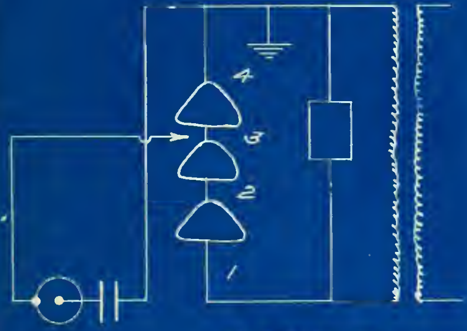
PLATE 8.



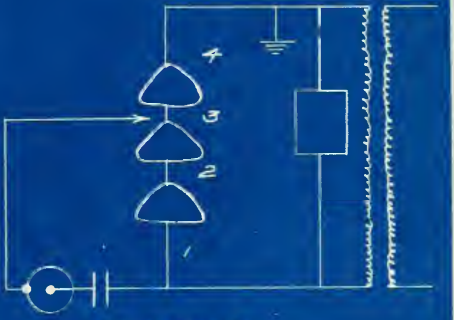
CASE 5.



CASE 6.



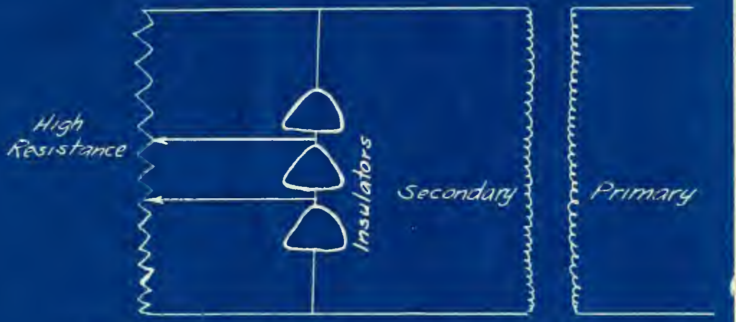
CASE 7.



CASE 8.

THESIS
DISTRIBUTION OF POTENTIAL OVER
HIGH TENSION INSULATORS
BY Kellie & Ruede 1910

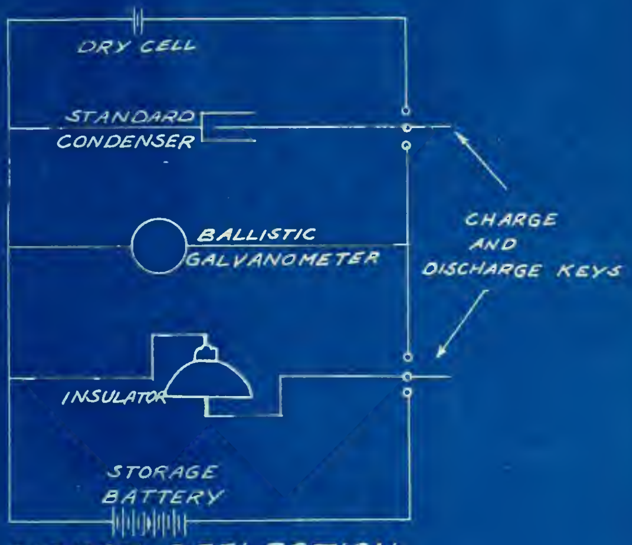
PLATE 9.



POTENTIOMETER METHOD
FOR
MEASURING DISTRIBUTION
OF POTENTIAL

THESIS
DISTRIBUTION OF POTENTIAL OVER
HIGH TENSION INSULATORS
BY Kallis & Reade 1910

PLATE 10.



DIRECT DEFLECTION
METHOD
FOR
MEASURING CAPACITY

THESIS
DISTRIBUTION OF POTENTIAL OVER
HIGH TENSION INSULATORS
BY [illegible] 1910

THESIS
DISTRIBUTION OF POTENTIAL OVER
HIGH TENSION INSULATORS
BY Kellie & Rude 1910

PLATE II.

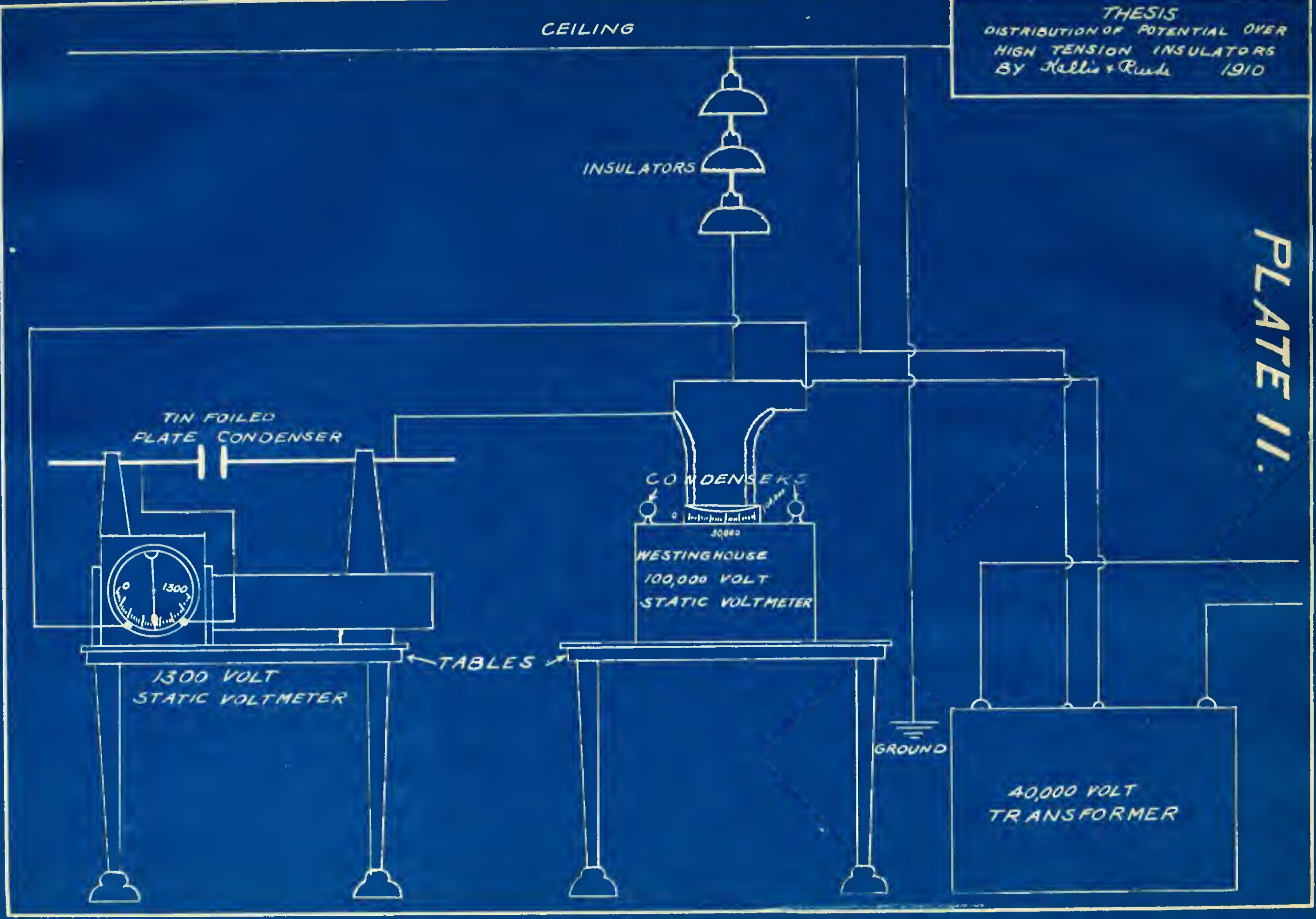


PLATE 12.

THESIS
DISTRIBUTION OF POTENTIAL OVER
HIGH TENSION INSULATORS
BY Kellie + Rude 1910